

Temporal Variations of High-Degree Solar p -Modes from GONG and MDI

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Abstract. We study temporal variations in the amplitudes and widths of high-degree acoustic modes in the quiet and active Sun by applying ring-diagram technique to the GONG+ and MDI Dopplergrams during the declining phase of cycle 23. The increase in amplitudes and decrease in line-widths in the declining phase of the solar activity is in agreement with previous studies. A similar solar cycle trend in the mode parameters is also seen in the quiet-Sun regions but with a reduced magnitude. Moreover, the amplitudes obtained from GONG+ data show long-term variations on top of the solar cycle trend.

1. Introduction

The global and local analysis of solar acoustic modes has shown that the mode amplitudes and lifetimes are anti-correlated with the solar activity level, and depend strongly on the local magnetic flux [1, 2, 3]. Most of the analyses have been done for average quantities without discrimination between quiet and active areas, while the solar cycle behavior of the quiet-Sun regions is not well understood. High-degree p -mode lifetimes measured in the quiet-Sun regions using cross-correlation analysis show variations with the activity cycle [4]. In the quiet Sun, no large-scale magnetic field concentrations, one of the potential damping sources, are present on the surface. Another explanation could be the activity-related variation of the convective properties near the solar surface. The studies of the solar cycle variations of the size of the solar granules so far arrive at contradictory conclusions [5, 6]. An attempt to mask strong surface activity and analyze high-degree p -mode amplitudes in the quiet-Sun regions at solar minimum and maximum indicated that the amplitude at solar minimum is higher than that at solar maximum [7], however, the effect introduced by the mask needs to be better understood. In this work we apply ring-diagram analysis to eight years of data to characterize the high-degree acoustic mode amplitudes and widths in the quiet and active Sun during declining phase of the activity cycle.

2. Data analysis

The mode parameters of the solar acoustic oscillations analyzed in this work are obtained from Global Oscillation Network Group (GONG) and Michelson Doppler Imager (MDI) high-resolution Dopplergrams for the period from 2001 to 2009 using the standard ring-diagram technique [8] of the GONG and MDI pipelines. The size of a standard patch in the ring analysis

is $15^\circ \times 15^\circ$. The most distant patches are centered at $52^\circ.5$ from the disk center. More recently the pipeline developed for the Helioseismic and Magnetic Imager (HMI) [9], applying both asymmetric [10] and symmetric [11] profiles fitting to derive the mode parameters, has also been used to analyze the MDI data, in the traditional MDI patch set. The results from both procedures are consistent, thus, here we show the symmetric profile fitting results only.

The Magnetic Activity Index (MAI) values are computed from MDI 96-minute magnetograms for the same time frame of Dopplergrams. The MAI is computed by averaging unsigned flux above 50 G and below 500 G to avoid contamination from noise in the measurements of the quiet-Sun flux values and saturation issues of the MDI magnetograms [12]. We define the quiet-Sun regions as those with MAI values below 5 G.

As discussed in [3], the amplitudes and widths fitted from the ring analysis need to be corrected for center-to-limb, residual B_0 -angle variations, and duty-cycle dependences. In our analysis, GONG data were restricted to duty cycle of 70% and higher. In contrast, MDI data have high duty cycle and therefore no selection criteria were used to reject the fitted parameters. In this work, only disk center patches were analyzed to avoid the foreshortening effects.

3. Results and discussion

The results for amplitudes and widths shown in this paper are for a multiplet $\ell = 440$, $n = 2$ ($\nu = 3.2$ mHz). We find that the correlation of this multiplet with other multiplets in the 2.5–3.5 mHz frequency range over solar activity cycle is higher than 70%.

3.1. Activity-related trend

The variations of amplitude and width as a function of time and MAI, computed from all patches and the quiet-Sun patches at the disk center using GONG data, are shown in Figure 1. According to the Mt. Wilson sunspot index data (see Figure 2), during most of the year 2008 the Sun was quiet with no or very few small sunspots appearing on the solar surface. Therefore, we took average of year 2008 consisting of 13 Carrington Rotations as a reference, and plotted the mode parameters relative to this mean value. The amplitudes increase by $\sim 10\%$ from the high solar activity period in 2001 till 2004. After this period, we find a long-term variation, but no clear association with activity cycle. It is interesting to note that the mode amplitude, derived from Variability of Solar Irradiance and Gravity Oscillations (VIRGO) and GONG data using global helioseismology technique, shows similar wiggles though they are small in amplitude relative to the extent of the solar cycle trend [13]. If we ignore the unexplained long-term variations, we can conclude that the mode amplitudes obtained in our study increased from 2001 to 2008 by $\sim 22\%$ in all patches and by $\sim 16\%$ in the quiet-Sun regions. The widths decreased from 2001 to about 2008 by $\sim 9\%$, then started showing a rising trend.

The variations in amplitude and width from MDI data (see Figure 1, top panels) show a solar cycle trend similar to that from GONG data. The long-term variations in the amplitudes obtained from GONG data are not seen in the MDI amplitudes. However, this could be due to the limited amount of data (only 135 days) that were analyzed with the MDI Dopplergrams. We plan to improve statistics on MDI data to confirm these results.

The decrease in amplitudes and increase in widths with increase in MAI (bottom panels of Figure 1) are consistent with known results from global and local analysis. The linear correlation analysis shows that the correlation coefficient between amplitude and MAI is -0.49 for all patches and -0.29 for the quiet-Sun patches. The correlation coefficient between width and MAI is 0.73 for all patches and 0.48 for the quiet-Sun patches.

Figure 2 shows the variation of the magnetic activity index over time. The MAI values of all patches at the disk center are well correlated with Mt. Wilson sunspot index. A weaker solar-cycle trend is also visible in the magnetic indices of the quiet-Sun patches. The solar cycle variation of the MAIs of the quiet-Sun regions computed from MDI magnetograms was also

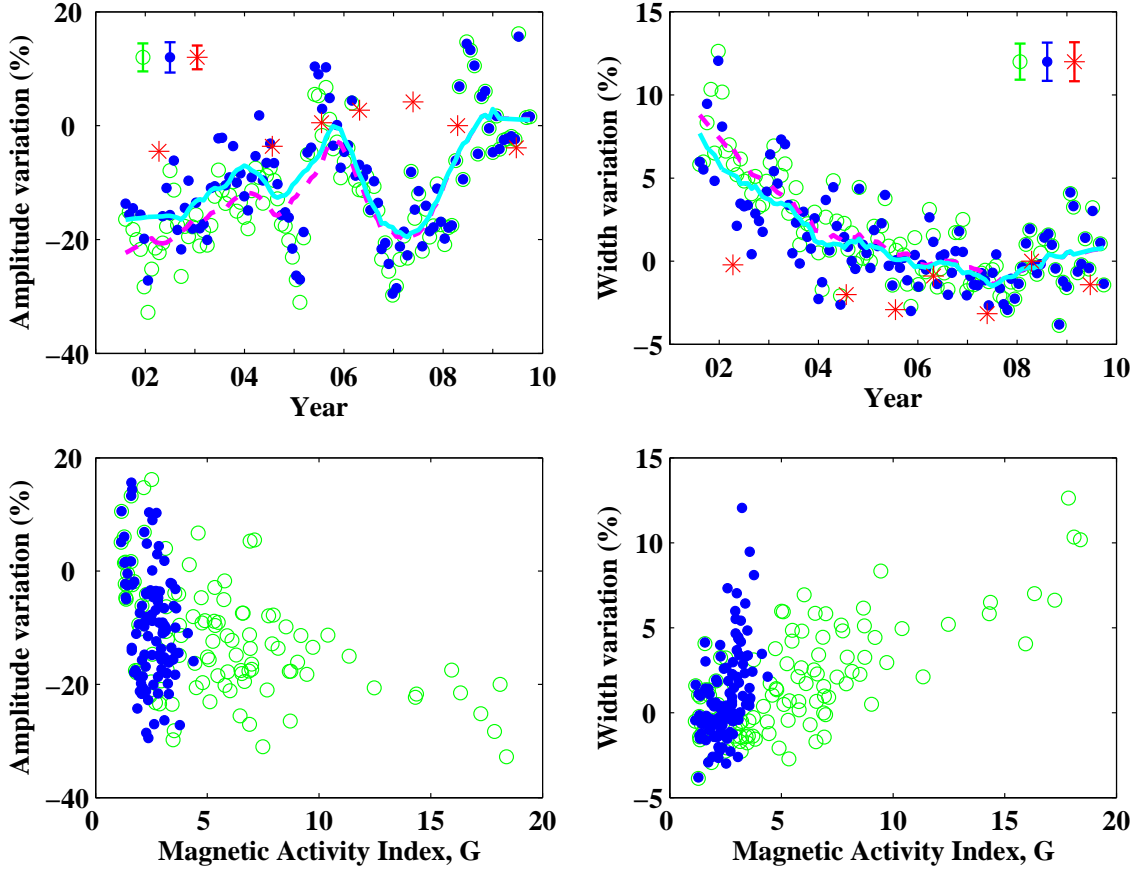


Figure 1. Variation of amplitude and width (relative to the mean value of 2008) as a function of time and MAI, computed in the quiet-Sun (closed blue circles) and all patches without MAI threshold (open green circles). The mode parameters are derived from disk center patches using GONG data. Each point is an average over one Carrington rotation. Solid light-blue and dashed magenta curves represent the temporally smoothed values in the quiet-Sun and all patches, respectively. Red stars show the amplitude and width variation as a function of time, computed from MDI data in all patches at the disk center. In this case, each point is an average over one year. The typical error bars for the measurements are shown in the top panels.

noted in [4] and could be due solar cycle variation of the strong-field component of the quiet-Sun network [14, 15]. This suggests that the magnetic field plays a role in the activity related variations of the acoustic mode parameters in the quiet Sun.

3.2. Long-term variations

In an attempt to understand the long-term variations, on top of the solar cycle trend, seen in the amplitudes computed from GONG data, we restrict our analysis to $2 \text{ G} \leq \text{MAI} \leq 3 \text{ G}$ patches. We notice the long-term variation in the amplitude but no dependence on magnetic activity. This leads to the conclusion that the variations are probably not related to solar activity cycle. Moreover, according to our preliminary estimates from the patches at higher latitudes, the variations are present up to the regions centered at $52^\circ.5$ in latitude. We plan to investigate this aspect in more detail after applying the necessary geometrical corrections.

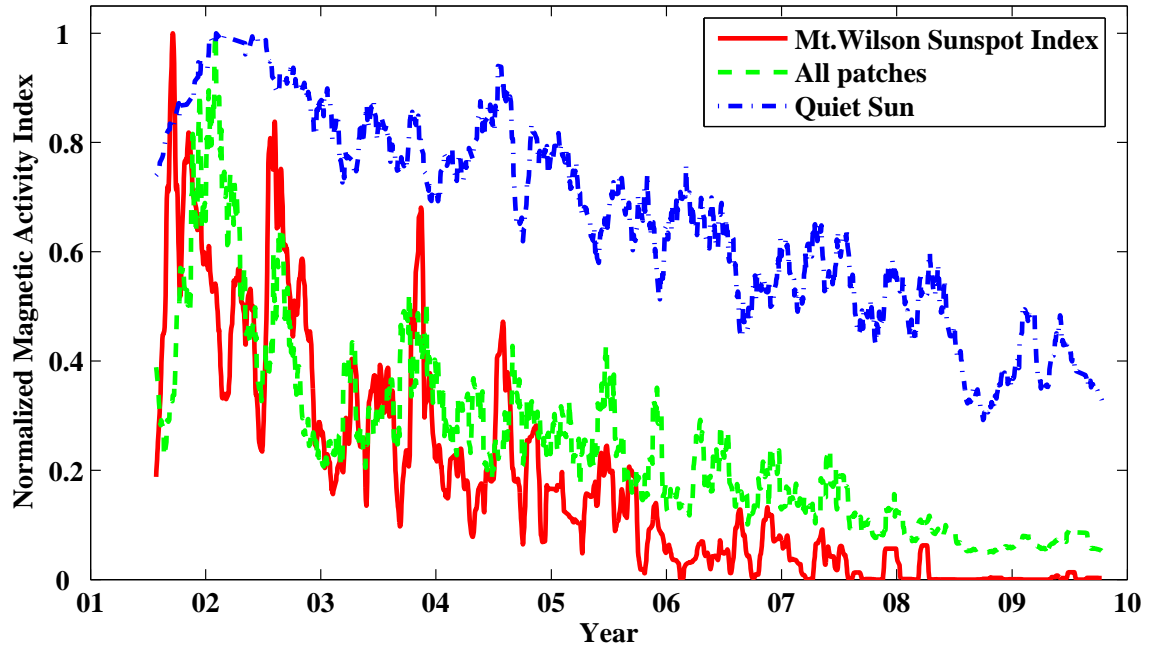


Figure 2. Normalized magnetic activity index, computed from MDI magnetograms in the quiet-Sun (dash-dot blue curve) and all regions (dashed green curve) at the disk center, plotted as a function of time. The solid red line represents the Mt.Wilson Sunspot Index. Note, that each curve is normalized to its maximum value to show the relative variation.

Acknowledgments

This work utilizes data obtained by the Global Oscillation Network Group (GONG) Program, managed by the National Solar Observatory, which is operated by AURA, Inc. under a cooperative agreement with the National Science Foundation. The data were acquired by instruments operated by the Big Bear Solar Observatory, High Altitude Observatory, Learmonth Solar Observatory, Udaipur Solar Observatory, Instituto de Astrofísica de Canarias, and Cerro Tololo Interamerican Observatory. SOHO is a mission of international cooperation between ESA and NASA.

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